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Smart integRation Of local energy sources and innovative storage for flexiBle, secure and cost-efficIent eNergy Supply ON industrialized islands

D 5.7 – D5.7 Ecological Impacts of ROBINSON on Eigerøy: Using acoustic monitoring to rapidly assess biodiversity

Lead partner: ERI, UHI North, West and Hebrides

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Executive summary

1. The Horizon 2020 project ROBINSON aims to drive forward the decarbonisation of industrialised islands by reducing fossil fuel consumption by developing, installing and integrating a number of new renewable energy devices. As a consequence of the associated infrastructure, there is the potential for ecological impacts.
2. Previous work (Deliverable 5.6: Desk-based scoping study of the potential impacts associated with the Renewable Energy Systems within ROBINSON) showed that robust analysis of the potential outcomes was challenging because of a lack of information on the environmental effects, as well as a lack of ecological data in the area.
3. To address the lack of ecological data, and to assess the extent to which passive acoustic monitoring can be used to rapidly assess biodiversity within an area, sufficient for use in an Ecological Impact Assessment (EcIA), we deployed ten acoustic recording units across a 2 x 1.5km area roughly surrounding the focal site on of Prina Protein on Eigerøy.
4. We collected 828 hours of acoustic data and using BirdNET analyser we were able to identify a total of 150 bird species present in the data from the acoustic recorders deployed across the area if interest. We also calculated the acoustic indices Acoustic Complexity Index (ACI), Bioacoustic Index (BI), and Normalised Difference Soundscape Index (NDSI) and created false colour plots to examine spatial and temporal patterns in the data.
5. Acoustic recorders were able to identify spatial and temporal variation in species richness around the site of the ROBINSON development on Eigerøy. Even over a small spatial scale, variation and patterns within the data were visible, demonstrating the ability of acoustic data to represent local biodiversity and enable rapid data collection.

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List of abbreviations

ACI: Acoustic Complexity Index

BI: Bioacoustics Index

EcIA: Ecological Impact Assessment

FFT: Fast Fourier Transform

LNG: Liquified Natural Gas

NDSI: Normalized Difference Soundscape Index

RED: Renewable Energy Device

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Introduction

The H2020 project 'smart integRation Of local energy sources and innovative storage for flexiBle, secure and cost-efficIent eNergy Supply ON industrialized islands' (ROBINSON) aims to demonstrate how to decarbonise industrialised islands i.e. decrease fossil fuel-derived energy usage, through the integration of multiple differing renewable energy devices (REDs), tied together by a smart management system.

Objective 6 of ROBINSON aims to 'demonstrate a significant positive impact on human health and the environment'. Work Package 5 supports this objective through life cycle analyses (LCA – T5.1) and ecological impact analysis (T5.4, which includes this deliverable). The ROBINSON project will reduce island reliance on fossil fuel consumption and therefore should reduce harmful greenhouse gas emissions, aiming to reduce CO2 emissions by 20% at the end of the project in 2024. Other positive environmental impacts include the conversion of wastewater, specifically from Prima Protein, the island's largest energy consumer, to biogas and digestate through an anaerobic digestion system, which diverts organic waste from being discharged into Egersund harbour. Prima Protein, a large producer of fishmeal and oil, was constructed in 2019 and since then has used LNG to power the majority of its operations.

T5.4 focuses on identifying and quantifying potential impacts of the ROBINSON system. Whilst the positive impact of the reduction of fossil fuel emissions is clear, the construction of new infrastructure means that there is the potential for negative environmental impact, which will vary according to the specific location and type of equipment being installed. The demonstration island of Eigerøy (Norway), as well as the two 'follower' islands of Crete (Greece) and the Western Isles (Scotland), vary in their energy needs, their geographical locations and their dominant industries meaning that the REDs employed will differ in each case.

As with any other development, this demonstration scenario requires an ecological impact assessment (EcIA), but previous work showed that robust analysis of the potential outcomes was challenging because of a lack of information on the precise outputs of the components and likely environmental effects, as well as a lack of ecological data in the area (Mitchell et al., 2024). This deliverable concentrates on the latter aspect i.e. a lack of ecological data in the area, and takes the form of an acoustic ecology or ecoacoustics study.

Ecoacoustics is defined as "a theoretical and applied discipline that studies sound along a broad range of spatial and temporal scales in order to tackle biodiversity and other ecological questions" (Sueur and Farina, 2015). A benefit of using sound is that it can be recorded remotely and autonomously using passive acoustic sensors, and these sensors can be deployed and synchronised to sample an area of interest according to a predefined schedule. Ecoacoustics has many applications including research for conservation biology, in the form of biodiversity assessments (Gibb et al., 2019; Sueur and Farina, 2015). An ecoacoustic approach was chosen here for the ability to be applied to multiple different future scenarios i.e., the islands within ROBINSON or data deficient areas, which may be the case for many remote, less-populated islands that do not have detailed data collected over the long term on species presence, that may help to predict ecological impacts. Furthermore, acoustic recorders have been shown in playback experiments to perform as well as human observers (Darras et al., 2018) and therefore may offer a rapid, cost-effective alternative to multiple fieldworkers.

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The aims of deliverable D5.7 were therefore to explore the feasibility of acoustic monitoring to i) rapidly collect data on biodiversity to help assess ecological impacts of the ROBINSON project; and ii) measure spatial and temporal variation in species diversity around the site of the planned ROBINSON development. Acoustic monitoring has been shown to be a useful monitoring tool, however we wanted to use methods previously developed and evaluate their ability to capture data and variation across smaller spatial scales i.e. the scale of the ROBINSON project.

Methods

Study location

Our study area was located on the island of Eigerøy (Rogaland, Norway). The island is separated from the mainland, by a narrow channel, approximately 145m at its shortest width, and 700m close to the town of Egersund. Our study was centred around a fish product factory, Prima Protein (58.438, 5.979), which was chosen as the demonstration site for the ROBINSON project ("smart integRation Of local energy sources and innovative storage for flexiBle, secure and cost-efficIent eNergy Supply ON industrialized islands"), being the main consumer of power on the island. Furthermore, the neighbouring seafood producer Pelagia is expanding its operations rapidly.

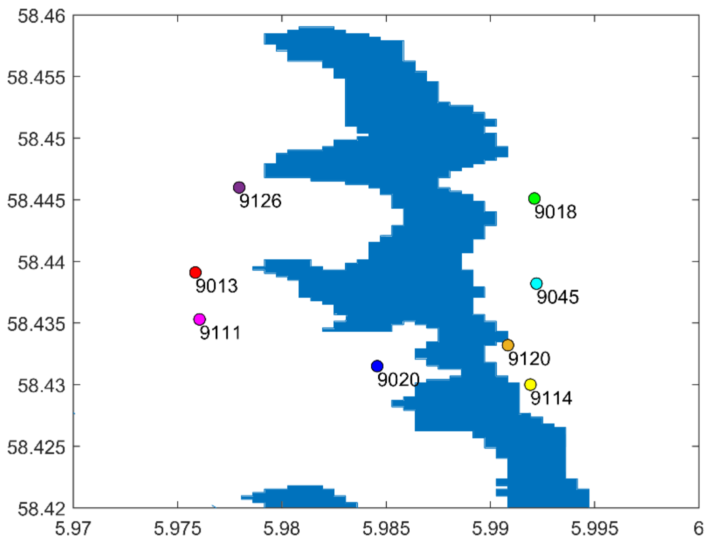

Figure 1: ROBINSON acoustic recorder locations (Table 1) with recorder colours as used in the acoustic indices' plots. Recorder colours: 09013 = red; 09018 = green; 09020 = blue; 09045 = cyan; 09111 = magenta; 09114 = yellow; 09120 = orange; 09126 = purple.

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Table 1: Robinson acoustic station locations between Eigerøy and Egersund in Norway.

Station	*latitude*	*longitude*	*Description*
09013	58.4391	5.97585	Hovlandsveien opposite side of the road
09018	58.4451	5.99211	Varberg hill, access above Jaerlighetsstien 1B
09020	58.4315	5.98457	Hamranveien
09045	58.4382	5.99221	Behind Pelagiaprotein
09111	58.4353	5.97605	Løyningsveien by bus stop
09114	58.43	5.99192	Pine trees along path
09120	58.4332	5.99084	Water's edge opposite 09020
09126	58.446	5.97795	On Grønehaugveien

Study focal species

Deliverable 5.6 (Desk-based scoping study of the potential impacts associated with the Renewable Energy Systems within ROBINSON) highlighted that locally on Eigerøy, there is a lack of consistent, standardised data on species presence, movements and behaviour, which means that the scale and strength of an environmental responses to the components of the renewable energy system are uncertain. Further, the weight of evidence analysis within deliverable 5.6 highlighted the importance of habitat requirements of species in dictating such responses to novel infrastructure, and therefore the importance of collecting and mapping species data on Eigerøy. One recommendation was standardised data collection, focusing on those taxa thought to be most vulnerable, such as sea ducks, and migrating birds and bats. Rather than focussing on migratory birds, in the first instance, to test method feasibility, we decided to focus on birds during the breeding season.

Data collection

To assess the extent to which passive acoustic monitoring can be used to rapidly assess the biodiversity of an area, sufficient for use in an EcIA, we distributed ten acoustic recording units (Song Meter Micro, Wildlife Acoustics) across a 2 x 1.5km area roughly surrounding the focal site i.e. Prima Protein (Figure 1 and Table 1). Positions were selected to form a grid around the focal site, so that we could measure spatial and temporal variation across a small scale. The units were placed in areas of vegetation, so that they were slightly insulated from road noise, or industrial noise from machinery and warehouse operations. Although testing before deployment indicated that the units had a detection range of close to 0.4 miles in open habitat, habitat type including vegetation structure can affect sound attenuation and thus the effectiveness of acoustic recorders (Darras et al., 2020).

Units were deployed from mid-May until the end of August 2023, and were set up identically on deployment, to record for a period of one hour at dawn, at a sample rate 48000Hz and a gain of 18dB.

Eight of the ten units recorded between 104 and 108 days (due to discrepancies in initial starting date). Unfortunately, issues with the replacement of batteries halfway through meant that two of the recorders only recorded 50% of the data compared with the other recorders, therefore the data from these recorders were not included in the analyses.

Analysis of acoustic recording data

Species richness

Acoustic recordings were analysed using BirdNET (GUI version 1.0.2, Model version V2.4) to identify bird species in the audio files recorded. BirdNET is a deep learning tool for avian diversity monitoring and was developed by the Cornell Lab of Ornithology and the Chemnitz University of Technology (Kahl et al., 2021). It is a free bird sound classifier that uses convolutional neural network algorithms to identify bird vocalizations in segments (3s) of audio recordings.

BirdNET was run using the multiple files mode and with the default parameter values for the sensitivity parameter (1.0) and with no overlap of prediction segments (0) but a minimum confidence score threshold of 0.7. The minimum confidence score was selected because Sethi et al. (2021) suggested a confidence score of 0.7-0.8, as lower confidence scores result in larger numbers of species being suggested, but this can reduce precision. Species selection was restricted to the area around Eigerøy, and year-round, therefore, sounds could not be classified as species from outside this range. Output files were saved in a csv format ready to be analysed in R (R Core Team, 2024). Output files contained information on the time (within the acoustic recording), species classified, as well as the confidence score. We were therefore able to investigate the number of species identified within the recordings as well as the total number of sounds classified to species level.

Acoustic indices

Data were analysed using MATLAB (version R2022b). Code and data samples by scikit-maad (Ulloa et al., 2021) and the Acoustic Index User's Guide (Bradfer-Lawrence et al., 2024b, 2024a) were used to write and test MATLAB scripts.

Acoustic indices are statistical measurements of spectral and temporal properties of a recorded sound scape derived from their spectrograms. These indices have been shown to correlate well with traditional diversity indices (Alcocer et al., 2022). We calculated acoustic indices for each minute of a 1-hour recording, meaning that for each minute in the hour, we retrieved a spectrogram that provided us with information to calculate the acoustic indices. Acoustic indices can be very sensitive to spectrogram settings such as Nspec (the number of frequency points used to calculate Fast Fourier Transform (FFT)), wspec (window of the spectrogram), and Noverlap (overlap between signal segments); following scikit-maad (Ulloa et al., 2021) we used 1024, hann(Nspec), and Nspec/2 respectively. There are many kinds of acoustic indices, and we selected Acoustic Complexity (ACI), Bioacoustics Index (BI) and Normalized Difference Soundscape Index (NDSI) because these three are used in the Acoustic Index User's Guide to calculate false colours (Bradfer-Lawrence et al., 2024b). Following scikit-maad (Ulloa et al., 2021) and Metcalf et al. (2022), we applied fourier transform with Nspec = 102, wspec = hann(Nspec), and Noverlap = Nspec/2 and did not apply any threshold before calculating the acoustic indices (Bradfer-Lawrence et al., 2024b; Ulloa et al., 2021).

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Acoustic Complexity Index (ACI)

The Acoustic Complexity (ACI) evaluates the relative absolute differences between two adjacent values of intensity in the frequency bins from a spectrogram by adding them up (Bradfer-Lawrence et al., 2024b). A file can be subdivided after FFT in clusters before summing (Pieretti et al., 2011), but this is not mandatory (Farina, 2019). Brownlie et al. (2020) use a cluster size of 5 s but we followed scikit-maad (Ulloa et al., 2021) and hence did not split a 1-minute recording (nparts = 1).

Bioacoustic Index (BI)

The Bioacoustics Index (BI) from a spectrogram is a measure of the area under the spectrogram curve for a frequency band. The calculation used in the soundecology R package (Villanueva-Rivera and Pijanowski, 2018) is based on Boelman et al. (2007). We used their method of deriving BI but like scikit-maad, we use the frequency band 2000 – 15000 Hz and Nspec of 1024 (Ulloa et al., 2021).

Normalized Difference Soundscape Index (NDSI)

The Normalized Difference Soundscape Index (NDSI) takes the sum of energy in biological frequencies (bioPh) and the sum of energy in anthropological frequencies (antroPh) to derive *bioPh−antroPh/bioPh+antroPh* (Brownlie et al., 2020; Farina, 2019; Kasten et al., 2012).

NDSI ranges between -1 (all anthropological) and +1 (all biological). Like scikit-maad we select the spectral bands anthrophony at 1-2 kHz and biophony at 2-11 kHz (Ulloa et al., 2021).

False colour plots

If we represent the three acoustic indices as ACI = red (R), BI = green (G), and NDSI = blue (B), the combination of the three specifies a unique colour (Metcalf et al., 2022). We rescaled the acoustic indices from minimum to maximum to from 0 to 1 over all the data in the comparison. Although the value of Nspec influences ACI and BI values, the relative differences in colour remain. Note that false colour will vary with the max and min of the acoustic indices in the dataset under consideration.

Results

Species richness

We collected 828 hours of acoustic data across eight acoustic recorders. These comprised one hour per day, and either 103 or 104 sampling days per recorder (Table 2). From these data, and with a minimum BirdNET confidence score of 0.7, 75258 individual sounds were classified by BirdNET (Table 2), representing 150 bird species (Table 3). Generally, there were more sounds classified in the first half of the sampling period, and this decreased towards the end of August. This appeared to be the case for the number of species detected from some of the recorders (09013 and 09045) but not for all (Figure 2). One noticeable feature of the data was that the number of sounds classified at acoustic recorder 09020 decreased dramatically in July, however, there did not appear to be a similar decrease in the number of species identified (Figure 2).

The median number of species identified from the acoustic data across the eight recorders was 72.5 and ranged between 41 and 86 (Table 3). The greatest number of species was detected by acoustic recorders 09020 and 09114; however, the greatest number of sounds classified was detected by acoustic recorder 09126 (Tables 2 and 3). 14 species were identified to be present across all eight recorders and these included species such as Dunnock (*Prunella modularis*), Eurasian Blackbird (*Turdus*

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merula) and Herring Gull (*Larus argentatus*) (Table 4). 40 species were identified at one of the eight recorders. Some of these species included Gray Partridge (*Perdix perdix*) and Ural Owl (*Strix uralensis*) which have never been observed in this part of Norway, as well as Black Guillemot (*Cepphus grylle*), a coastal bird recorded in woodland, were unexpected; this will be further explored in the discussion.

Table 2: Number of classified sounds identified by BirdNET from the acoustic recordings

Acoustic recorder ID	Sampling days (1 hour per day)	Classified sounds (total)	Classified sounds per day (median)	Interquartile range	Classified sounds per day (min.)	Classified sounds per day (max.)
09013	104	11588	58.5	18.5-151	1	725
09018	103	6495	42.5	12.75-109	1	284
09020	104	14701	39.5	15-300.2	1	609
09045	103	4401	29	5.75-69.25	1	329
09111	104	2880	14	6-34.75	1	167
09114	103	9393	79.5	28.25-141	2	398
09120	103	3077	20.5	9.75-46.25	1	197
09126	104	22723	205	65-351	1	780

Table 3: Number of species identified by BirdNET from the acoustic recordings

Acoustic recorder ID	Sampling days (1 hour per day)	Species detected (total)	Species per day (median)	Interquartile range	Species per day (min.)	Species per day (max.)
09013	104	75	7	4-10	1	16
09018	103	49	5.5	4-7	1	11
09020	104	86	7	5.25-8.75	1	12
09045	103	41	4	2-6.25	1	14
09111	104	75	4	3-5	1	12
09114	103	85	8	5-10	1	18
09120	103	53	4.5	3-7	1	13
09126	104	70	8	6-9	1	15

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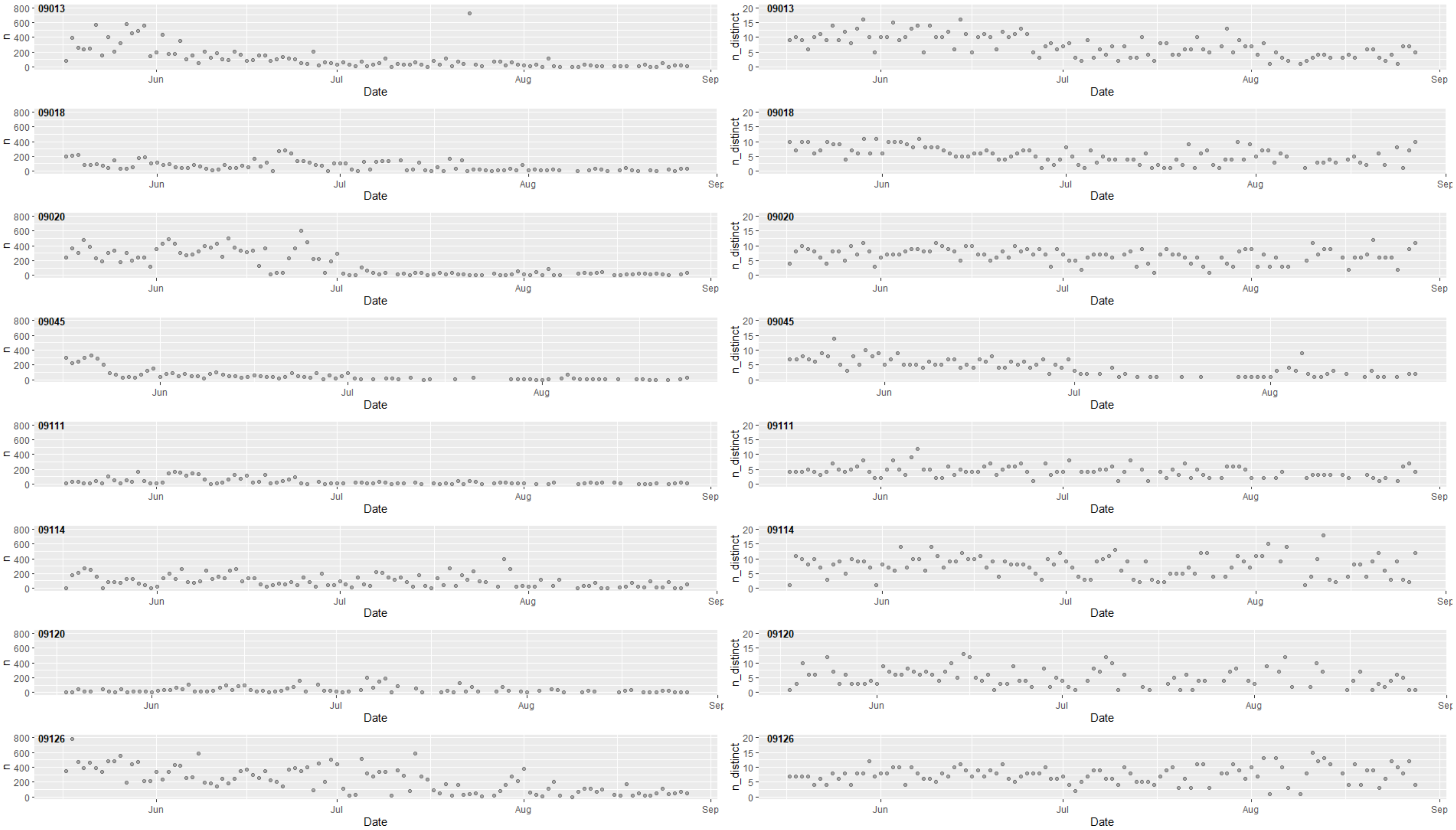
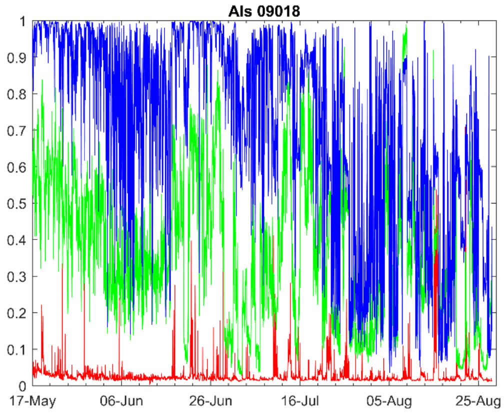


Figure 2: Number of sounds classified (n – left panels) and species identified (n_distinct – right panels) by BirdNET from the acoustic recorders (recorder ID in top left of plots).

Acoustic indices

We calculated the acoustic indices ACI, BI, and NDSI for all acoustic recorders and all days. Figure 3 shows normalised ACI, BI, and NDSI for acoustic recorder 09018, for each minute (top) and for daily 1-hr averages (bottom). Figure 4 shows the corresponding false colour plot. The plots for all acoustic recorders are shown in respective Figures 5-7.



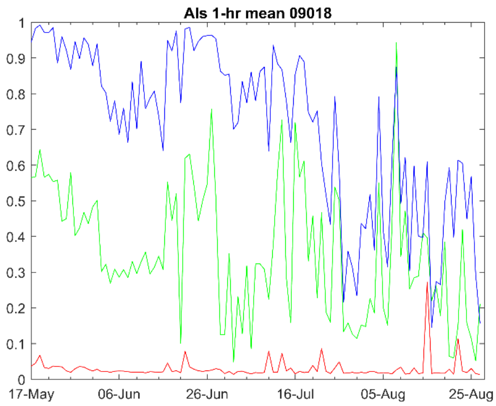


Figure 3: Line plots with acoustic indices of each minute scaled to max and min of all acoustic recorder (y axis). ACI = Red, BI = Green, NDSI = Blue. Showing for acoustic recorder 09018 and (top) for each minute, and (b) for daily 1-hr averages.

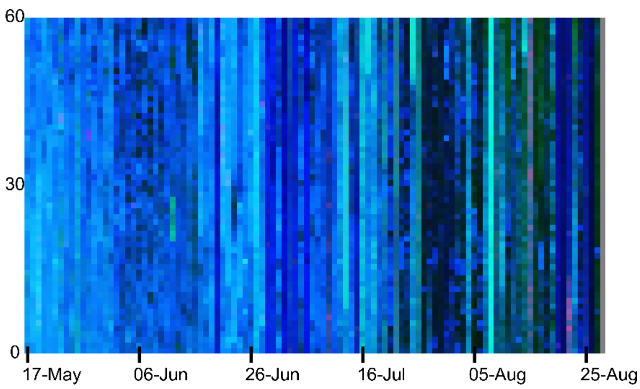


Figure 4: False colour plots for acoustic recorder 09018 per minute with acoustic indices scaled to max and min of all acoustic recorders (y axis). ACI = Red, BI = Green, NDSI = Blue. Grey indicates no data. Fourier transform: Nspec = 1024.

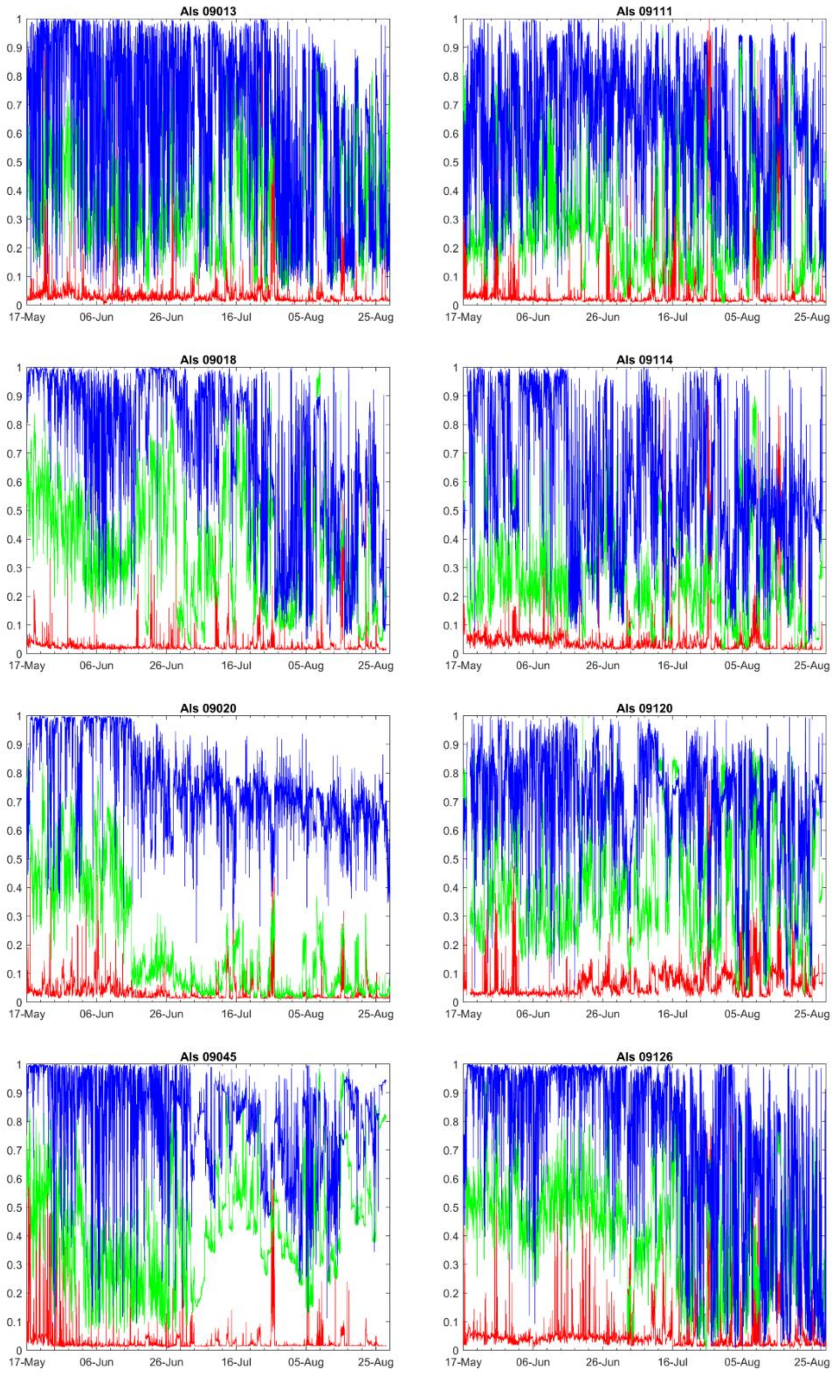


Figure 5: Line plots with acoustic indices of each minute scaled to max and min of all acoustic recorders (y axis). ACI = Red, BI = Green, NDSI = Blue.

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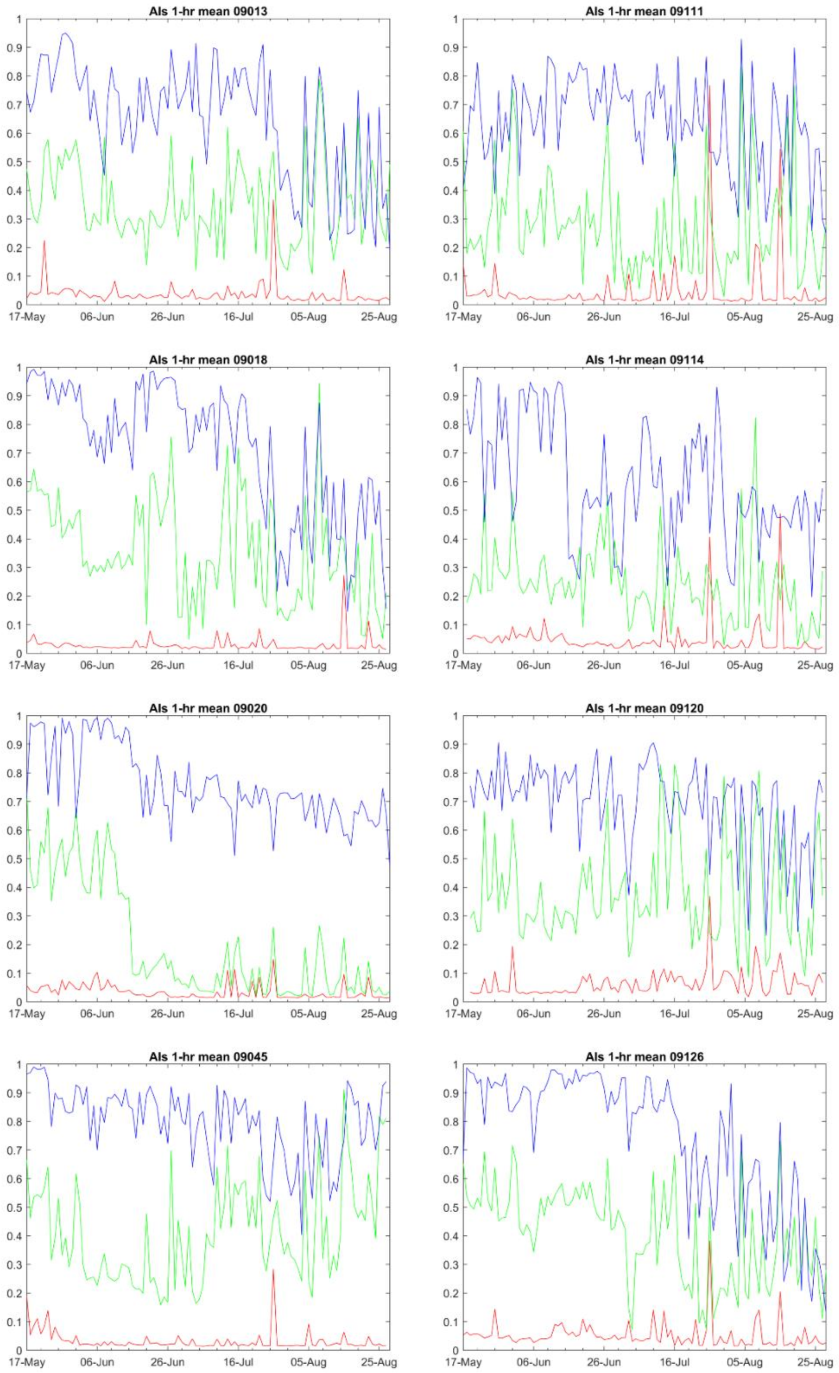

Figure 6: Line plots with acoustic indices scaled to max and min of all acoustic recorders averaged over each daily hour (y axis). ACI = Red, BI = Green, NDSI = Blue.

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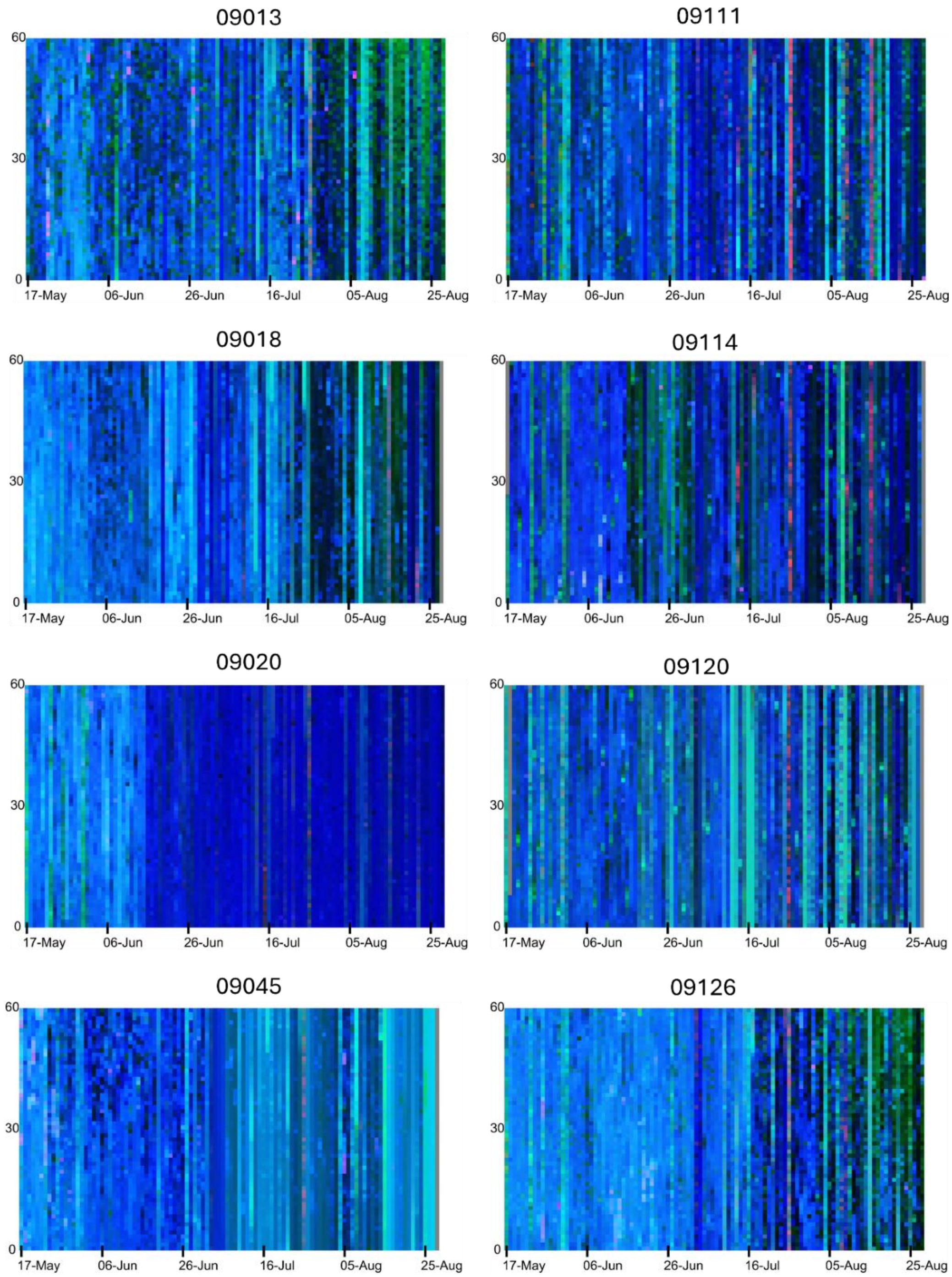

Figure 7: False Colour plots with acoustic indices scaled to max and min of all acoustic recorders (y axis). ACI = Red, BI = Green, NDSI = Blue, NaN = grey.

We can visualise the acoustic indices for all acoustic recorders in one figure. Figure 8 shows BI for each minute (top), averaged over 1 hour (middle), and moving average over 7 days (bottom), while Figure 9 shows 1-hour std of BI (top) and 7-day moving average of std. Figure 8 top and middle are shown in Fig. 10, and Fig. 8. bottom and Fig. 9. bottom in Fig. 11.

Some very high ACI values affected the normalization of ACI for which the values were generally lower (Fig. 5). This produced low normalized ACI values and hence showed less red in the false colour images. Where the colour is more dominated by red (e.g. 26th July, Fig. A3) this indicated more complex sounds and the sound of rain was suspected (Bradfer-Lawrence et al., 2024b).

Acoustic Complexity Index (ACI)

ACI over all stations ranged from 292 to 603; as there were few higher measurements (~600, the mean was 306), normalized ACI values were low (Figure 6). Consequently, the false colour plots are in general strongly blue-green coloured (Figure 7). ACI is low when there is no acoustic activity or high acoustic activity with continuous background noise (Ulloa et al., 2021). Conversely, ACI is high when acoustic activity is medium, with sounds well above the background noise (Ulloa et al., 2021). There were ACI spikes around 26th July at most stations, smaller ones 9 and 15 August, caused by the sound of a passing rainstorms.

Bioacoustic Index (BI)

BI ranged between 8 and 120 and was 43 on average (figs. 5 & 6). A marked drop was seen at station 09020 around 16 June resulting in blue false colours thereafter (Figure 7) and suggesting the overall biological noise decreased. It is possible that something happened to the acoustic recorder.

Normalised Difference Soundscape Index (NDSI)

NDSI varied between -0.93 and 1.00 (mean = 0.42). This indicated that the overall soundscape was more biophonic than anthrophonic. NDSI appeared to drop for the two most northerly stations 09126, 09013, and 09018 after around 16th July (Fig. 6). This related to a greener hue in the false colour images (Fig. 7). 1-hour averages of bioPh and antroPh for each station (Fig. 12) show clearer patterns and spikes of biological and anthropogenic sounds.

False colour plots

Acoustic data were recorded for only one hour at dawn and we could not observe any obvious patterns or evidence change during this hour. Sporadic rain events were clearly marked by red colours (Fig. 7). False colour plots proved a useful method and inter-station differences are clearly visible using this method; some stations (09013, 09018, 09020, 09126) showed lighter colour for the first three weeks of recording. There was an obvious change in colour for recorder 09020.

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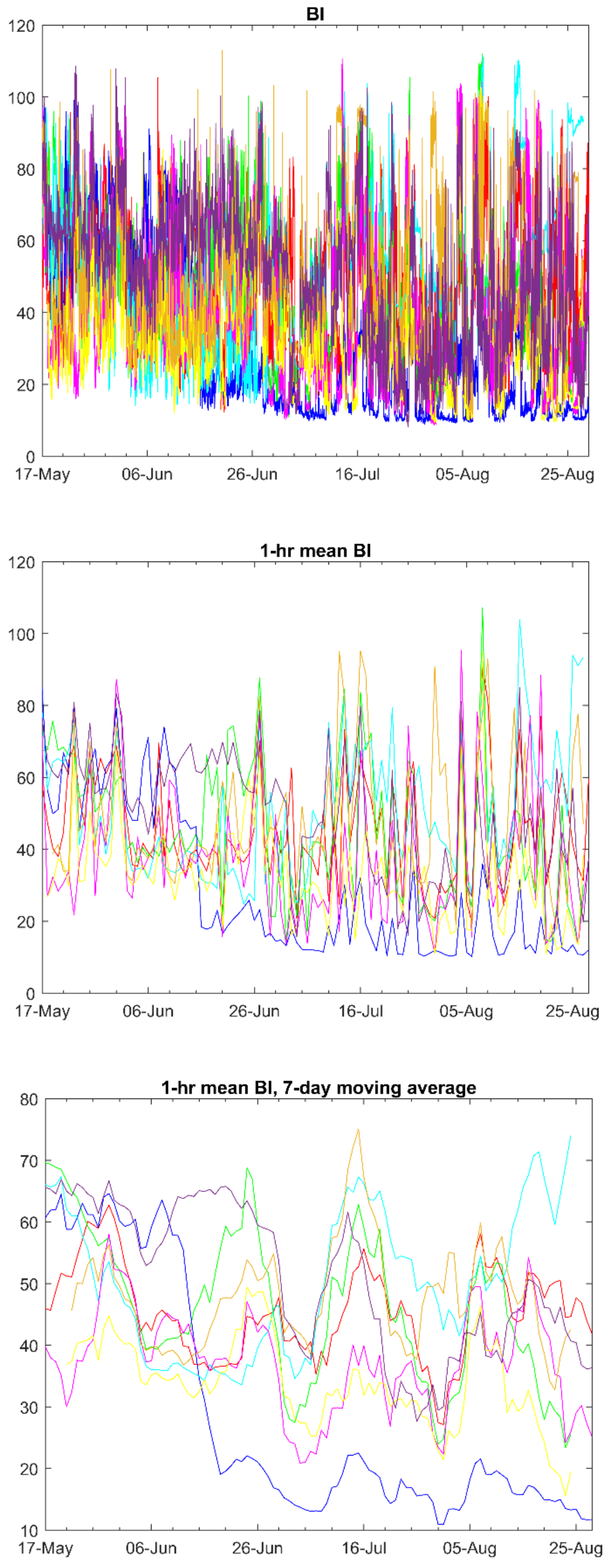

Figure 8: Bioacoustic Index (y axis) plotted for all stations, and for (top) every minute, (middle) every daily 1-hr average, and (bottom) 7-days moving mean of daily 1-hour averages. Fourier transform: Nspec = 1024. Acoustic recorder colours: 09013 = red; 09018 = green; 09020 = blue; 09045 = cyan; 09111 = magenta; 09114 = yellow; 09120 = orange; 09126 = purple.

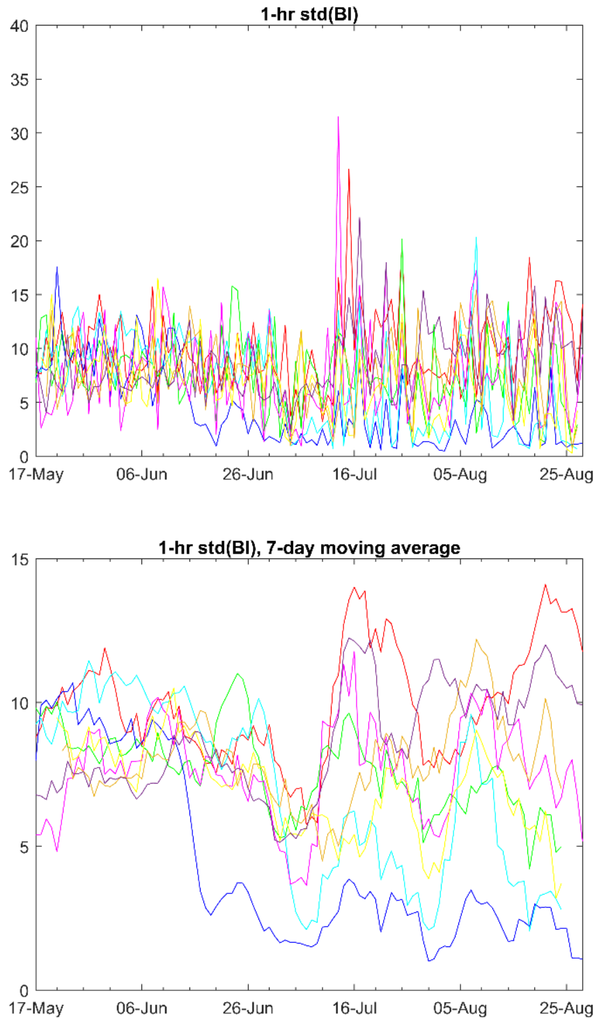

Figure 9: Standard deviation (std) of Bioacoustic Index (y axis) plotted for all stations, for (top) every daily 1-hr average, and (bottom) 7-days moving mean of daily 1-hour standard deviations. Station colours: 09013 = red; 09018 = green; 09020 = blue; 09045 = cyan; 09111 = magenta; 09114 = yellow; 09120 = orange; 09126 = purple.

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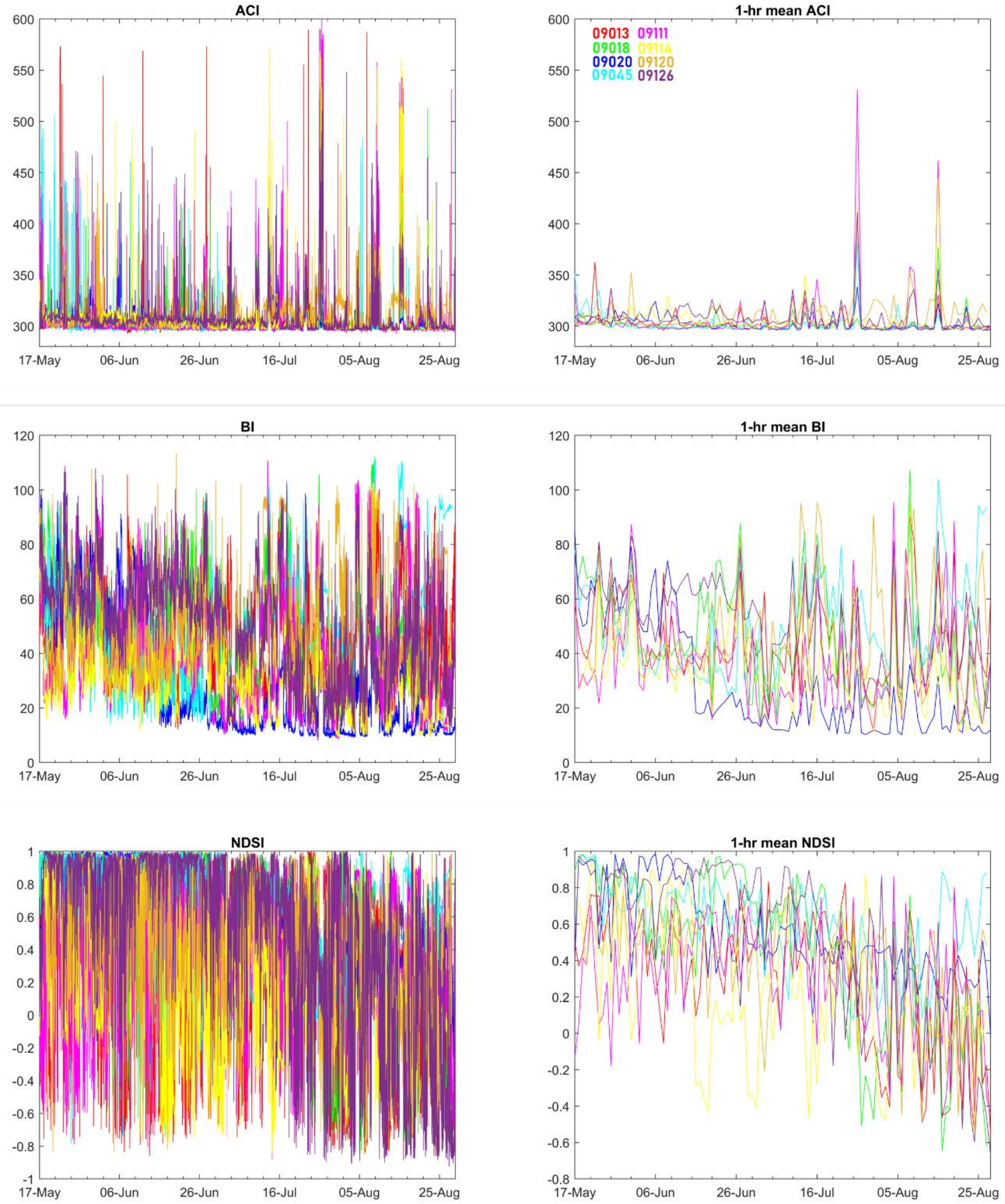

Figure 10: Acoustic indices (y axis), (top) ACI, (middle) BI, and (bottom) NDSI, and (left) for each minute and (right) for daily 1-hour averages. Station colours: 09013 = red; 09018 = green; 09020 = blue; 09045 = cyan; 09111 = magenta; 09114 = yellow; 09120 = orange; 09126 = purple.

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Figure 11: Standard deviations of acoustic indices, (top) ACI, (middle) BI, and (bottom) NDSI, showing moving 7-day averages over (left) for daily 1-hour averages (right) for daily 1-hour standard deviations.

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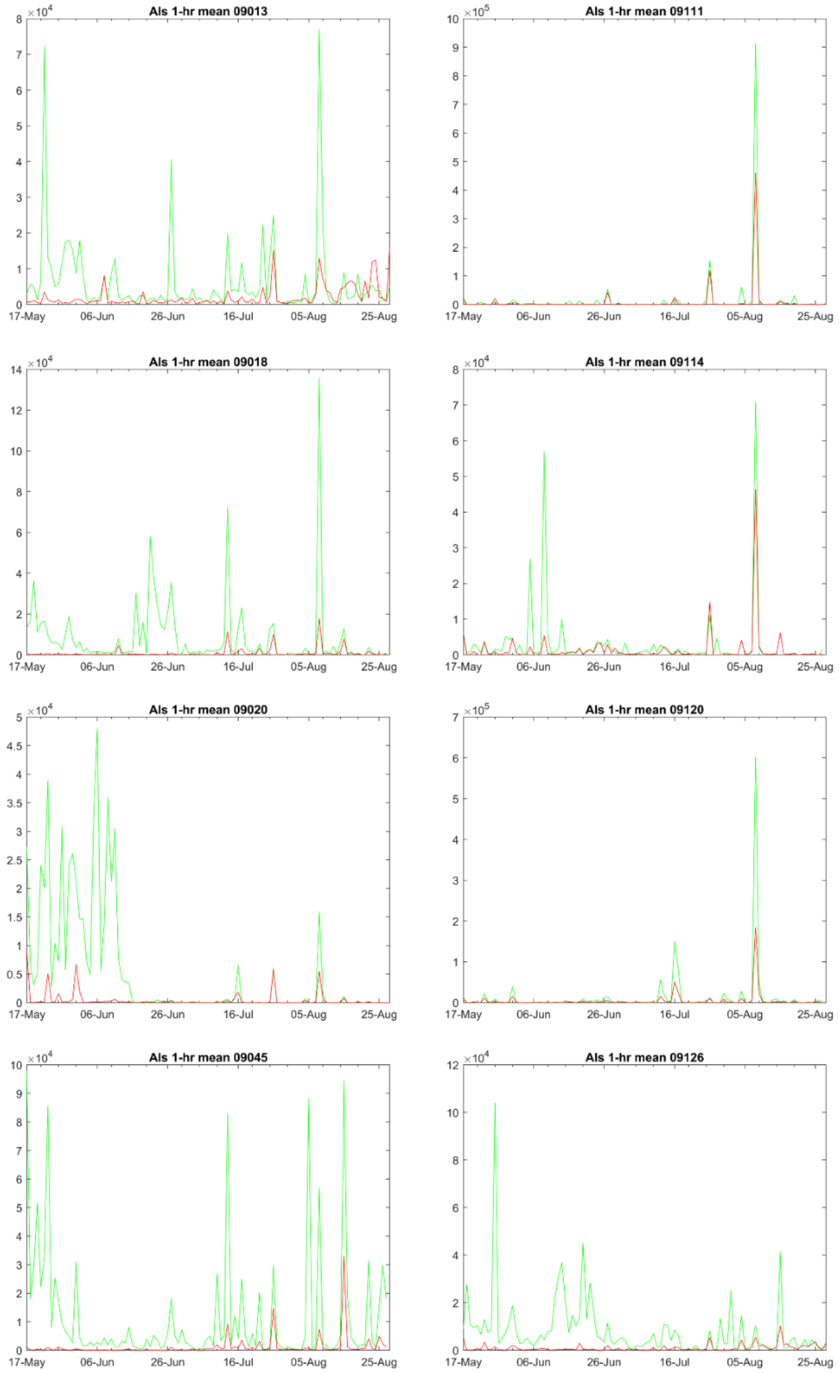

Figure 12: Line plots with bioPh (green) and antroPh (red) averaged over each daily hour. Fourier transform: Nspec = 1024, no threshold applied.

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Discussion

Species richness

The aim of this study was to explore the feasibility of acoustic monitoring to i) rapidly collect data on biodiversity to help assess ecological impacts of the ROBINSON project; and ii) measure spatial and temporal variation in species diversity around the site of the planned ROBINSON development.

Using BirdNET we were able to identify a total of 150 bird species present in the data from the eight acoustic recorders deployed across the area if interest. Unfortunately, two of the original 10 recorders did not collect appropriate data, and one of these was the recorder closest to Prima Protein and the ROBINSON projects site of development. From the remainder, recorders 09013 and 09111 were closest to Prima Protein and although fewest sounds were classified from 09111, the number of species detected was not significantly reduced nor fewer than at other recorders, nor were they unexpectedly higher, i.e. suggesting the area around Prima Protein was more species diverse.

Our aim was to collect data on biodiversity, and we achieved this in terms of measuring number of species; however, using acoustics alone it was not possible to collect data on abundance. We are unable to tell from the data, and using the methods document in this report, if the sounds detected and classified for one species at a recording site were from one individual or many. Therefore, we only have presence data. Despite this, we were able to report which species were detected at all sites rather than at one site, and document which sites have more or fewer species. Another improvement which could have been implemented with additional resources would have been to undertake point counts using human observers at the sites of the acoustic recorders to ground truth the acoustic data collected and verify the species classification by BirdNET. This would also have allowed acoustic diversity in the form of the acoustic indices to be linked to species diversity.

Of the 150 species classified and identified by BirdNET it is likely that some of these were incorrect. We did not remove these species as it was understood that all could technically have been present in Norway (i.e. a previous Norwegian record), but may have been unlikely due to the location and associated habitat or the time of year. It is therefore likely that the species inventory could be modified and reduced in several ways. For unexpected results, it would be possible to go back through the data and inspect which recorder a species was identified at, and if the habitat was likely for that species, or indeed if the sound recorded did indeed sound like the species assigned at classification by BirdNET. This is known as 'sound-truthing' but was not possible within the timeframe of this project. Furthermore, it would be possible to check if the species is known to breed in Norway or is a migrant. As our recording period would have overlapped with the beginning of migration for some species, it is possible that species passing through the area were captured in the recordings.

In this study we were able to record acoustic data and identify species presence across the area of interest, but we did not then further link this to habitat or other relevant environmental or geographical variables due to the small spatial scale of the study. However, for larger sites this would be possible and would produce a more informed picture of the presence of species of interest.

Acoustic indices

We used acoustic indices and false colour plots as a method to observe spatial and temporal patterns, within and between the acoustic data recording sites. However, as the acoustic indices are highly

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dependent on the parameters of the spectrogram (e.g., Nspec), it is difficult to compare the values we obtained within this project with examples from literature. Additionally, we only recorded acoustic data for one hour after dawn which restricted the amount of time over which we could distinguish changes in values (Bradfer-Lawrence et al., 2024b).

Examining the false colour plots we did not identify striking temporal patterns; however, it appeared that NDSI decreases across the sampling period, suggesting more anthropogenic sound than biological sound. This is in line with changes in breeding behaviour of birds, which vocalise more during the early part of the breeding season and less as the summer progresses. It was also possible to see meteorological events in the data such a rain (red in the false colour plots) recorded in multiple acoustic recorders, likely due to the restricted spatial scale of the study.

One noticeable feature of the data is from record 09020 for which the bioacoustics index decreased suddenly in mid-June. When listening to the raw acoustic data it is noticeable that the sound level drops. Therefore, it might have been possible that something happened to the microphone of the recorder to distort the recordings, although this was not noticed in the field on retrieval of the recording equipment.

From our results, it appears tat it is clearer to interpret the acoustic indices when averaged per hour over a moving window, thus demonstrating that longer term recording is likely more useful. Further extended recording throughout the 24-hour period would also allow for the inclusion of nocturnal species.

Conclusions

Acoustic recorders were able to identify spatial and temporal variation in species richness around the site of the ROBINSON development on Eigerøy. Even over a small spatial scale, variation and patterns within the data were visible, demonstrating their ability to represent local biodiversity through rapid data collection.

In the long term, acoustic recording units could be placed around the site of Prima Protein to collect data after the components have been fully installed, to track post-installation bird species change. This would produce information related to increased noise produced by the additional components, one of the main potential effects of the ROBINSON project (Mitchell et al., 2024).

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Appendix

Table 4: Bird species detected at the different acoustic recorders

Common name	Scientific name	09013	09018	09020	09045	09111	09114	09120	09126	Total
Dunnock	*Prunella modularis*	1	1	1	1	1	1	1	1	8
Eurasian Blackbird	*Turdus merula*	1	1	1	1	1	1	1	1	8
Great Tit	*Parus major*	1	1	1	1	1	1	1	1	8
Common Chiffchaff	*Phylloscopus collybita*	1	1	1	1	1	1	1	1	8
Carrion Crow	*Corvus corone*	1	1	1	1	1	1	1	1	8
Eurasian Blue Tit	*Cyanistes caeruleus*	1	1	1	1	1	1	1	1	8
Eurasian Siskin	*Spinus spinus*	1	1	1	1	1	1	1	1	8
Spotted Flycatcher	*Muscicapa striata*	1	1	1	1	1	1	1	1	8
Herring Gull	*Larus argentatus*	1	1	1	1	1	1	1	1	8
Eurasian Wren	*Troglodytes troglodytes*	1	1	1	1	1	1	1	1	8
European Robin	*Erithacus rubecula*	1	1	1	1	1	1	1	1	8
Great Bittern	*Botaurus stellaris*	1	1	1	1	1	1	1	1	8
Grey Heron	*Ardea cinerea*	1	1	1	1	1	1	1	1	8
Common Kingfisher	*Alcedo atthis*	1	1	1	1	1	1	1	1	8
Willow Warbler	*Phylloscopus trochilus*	1	1	1	1	0	1	1	1	7

Common Chaffinch	*Fringilla coelebs*	1	0	1	1	1	1	1	1	7
European Pied Flycatcher	*Ficedula hypoleuca*	1	1	1	1	0	1	1	1	7
Eurasian Blackcap	*Sylvia atricapilla*	1	1	1	1	0	1	1	1	7
Gray Wagtail	*Motacilla cinerea*	1	1	1	1	1	1	0	1	7
Eurasian Oystercatcher	*Haematopus ostralegus*	1	1	1	0	1	1	1	1	7
Common Swift	*Apus apus*	1	1	0	1	1	1	1	1	7
Tree Pipit	*Anthus trivialis*	1	0	1	1	1	1	1	1	7
Redwing	*Turdus iliacus*	1	1	1	0	1	1	1	1	7
Hooded Crow	*Corvus cornix*	1	1	1	1	1	0	1	1	7
Common Buzzard	*Buteo buteo*	1	1	1	1	1	1	0	1	7
Leach's Storm-Petrel	*Hydrobates leucorhous*	1	0	1	1	1	1	1	1	7
Eurasian Curlew	*Numenius arquata*	1	1	1	0	1	1	1	1	7
Common Grasshopper-Warbler	*Locustella naevia*	0	1	1	1	1	1	1	1	7
Eurasian Magpie	*Pica pica*	0	1	1	1	1	1	1	1	7
Lesser Redpoll	*Acanthis cabaret*	1	1	1	0	1	1	0	1	6
Garden Warbler	*Sylvia borin*	1	1	1	1	1	0	0	1	6
Eurasian Green Woodpecker	*Picus viridis*	1	1	1	0	0	1	1	1	6
Long-tailed Tit	*Aegithalos caudatus*	1	1	0	1	0	1	1	1	6

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Graylag Goose	*Anser anser*	1	0	1	0	1	1	1	1	6
Tawny Owl	*Strix aluco*	1	0	1	1	1	1	0	1	6
Eurasian Nightjar	*Caprimulgus europaeus*	1	1	1	1	1	1	0	0	6
Eurasian Nuthatch	*Sitta europaea*	0	1	1	1	0	1	1	1	6
Common Redpoll	*Acanthis flammea*	1	1	1	0	1	0	0	1	5
Common Gull	*Larus canus*	1	0	0	0	1	1	1	1	5
Rook	*Corvus frugilegus*	1	0	0	1	1	0	1	1	5
Icterine Warbler	*Hippolais icterina*	1	1	1	1	0	0	0	1	5
Lesser Black-backed Gull	*Larus fuscus*	1	0	0	0	1	1	1	1	5
Hawfinch	*Coccothraustes coccothraustes*	1	0	1	0	1	1	0	1	5
Great Black-backed Gull	*Larus marinus*	1	0	1	0	1	1	1	0	5
Red-breasted Flycatcher	*Ficedula parva*	0	1	0	1	0	1	1	1	5
Mistle Thrush	*Turdus viscivorus*	0	1	1	0	1	1	0	1	5
Song Thrush	*Turdus philomelos*	0	1	1	1	0	1	0	1	5
Common Crane	*Grus grus*	0	1	0	1	1	1	1	0	5
Lesser Whitethroat	*Curruca curruca*	1	0	1	0	1	1	0	0	4
House Sparrow	*Passer domesticus*	1	1	1	0	1	0	0	0	4
American Pipit	*Anthus rubescens*	1	0	1	0	1	1	0	0	4

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Black Redstart	*Phoenicurus ochruros*	1	0	1	0	0	1	0	1	4
European Greenfinch	*Chloris chloris*	1	0	1	1	0	0	0	1	4
Mallard	*Anas platyrhynchos*	1	0	1	0	0	1	1	0	4
Eurasian Wigeon	*Mareca penelope*	1	0	0	0	1	1	1	0	4
Eurasian Coot	*Fulica atra*	1	0	0	0	1	1	1	0	4
Eurasian Bullfinch	*Pyrrhula pyrrhula*	1	0	1	0	1	1	0	0	4
Common Sandpiper	*Actitis hypoleucos*	1	0	0	0	1	1	1	0	4
Rustic Bunting	*Emberiza rustica*	1	1	1	0	0	1	0	0	4
White Wagtail	*Motacilla alba*	1	0	0	0	1	1	0	1	4
Bohemian Waxwing	*Bombycilla garrulus*	1	1	0	1	0	1	0	0	4
Eurasian Treecreeper	*Certhia familiaris*	0	1	0	0	0	1	1	1	4
Coal Tit	*Periparus ater*	0	1	0	0	1	1	0	1	4
Goldcrest	*Regulus regulus*	0	0	1	0	0	1	1	1	4
Green-winged Teal	*Anas crecca*	0	0	1	0	1	1	1	0	4
Greater Whitethroat	*Curruca communis*	1	0	0	0	1	0	0	1	3
Common Redstart	*Phoenicurus phoenicurus*	1	0	1	0	0	1	0	0	3
European Goldfinch	*Carduelis carduelis*	1	0	1	0	0	1	0	0	3
Eurasian Linnet	*Linaria cannabina*	1	0	0	1	1	0	0	0	3

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Crested Tit	*Lophophanes cristatus*	1	0	0	0	0	1	0	1	3
Red Kite	*Milvus milvus*	1	0	0	0	1	1	0	0	3
Whooper Swan	*Cygnus cygnus*	1	0	0	0	0	0	1	1	3
Common Raven	*Corvus corax*	1	0	0	0	0	1	0	1	3
Common Greenshank	*Tringa nebularia*	1	0	1	0	1	0	0	0	3
Great Spotted Woodpecker	*Dendrocopos major*	1	0	1	0	0	0	0	1	3
Common Quail	*Coturnix coturnix*	0	1	1	0	0	0	0	1	3
Common Ringed Plover	*Charadrius hiaticula*	0	1	1	0	1	0	0	0	3
Common Cuckoo	*Cuculus canorus*	0	0	1	0	1	1	0	0	3
Green Sandpiper	*Tringa ochropus*	0	0	1	0	0	1	0	1	3
Tundra Swan	*Cygnus columbianus*	0	0	1	0	1	1	0	0	3
Common Scoter	*Melanitta nigra*	0	0	0	0	0	1	1	1	3
Eurasian Kestrel	*Falco tinnunculus*	1	0	0	0	0	1	0	0	2
White-winged Crossbill	*Loxia leucoptera*	1	0	1	0	0	0	0	0	2
Gray-headed Woodpecker	*Picus canus*	1	0	0	0	0	0	0	1	2
Fieldfare	*Turdus pilaris*	1	1	0	0	0	0	0	0	2
Black-legged Kittiwake	*Rissa tridactyla*	1	0	0	0	1	0	0	0	2
Eurasian Jackdaw	*Corvus monedula*	1	0	0	0	0	1	0	0	2

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Eurasian Pygmy-Owl	*Glaucidium passerinum*	1	0	1	0	0	0	0	0	2
Boreal Owl	*Aegolius funereus*	0	1	1	0	0	0	0	0	2
Northern Goshawk	*Accipiter gentilis*	0	1	1	0	0	0	0	0	2
Barn Swallow	*Hirundo rustica*	0	0	1	0	1	0	0	0	2
Western Capercaillie	*Tetrao urogallus*	0	0	1	0	0	1	0	0	2
Eurasian Collared-Dove	*Streptopelia decaocto*	0	0	1	0	0	0	0	1	2
Hazel Grouse	*Tetrastes bonasia*	0	0	1	1	0	0	0	0	2
Eurasian Dotterel	*Charadrius morinellus*	0	0	1	0	0	1	0	0	2
Common Wood-Pigeon	*Columba palumbus*	0	0	1	0	0	0	0	1	2
European Golden-Plover	*Pluvialis apricaria*	0	0	1	0	1	0	0	0	2
Little Ringed Plover	*Charadrius dubius*	0	0	1	0	1	0	0	0	2
Black-bellied Plover	*Pluvialis squatarola*	0	0	1	0	1	0	0	0	2
Common Redshank	*Tringa totanus*	0	0	1	0	0	1	0	0	2
Pied Avocet	*Recurvirostra avosetta*	0	0	1	0	1	0	0	0	2
Spotted Crake	*Porzana porzana*	0	0	1	0	0	1	0	0	2
Eurasian Woodcock	*Scolopax rusticola*	0	0	1	0	0	0	0	1	2
Red Crossbill	*Loxia curvirostra*	0	0	1	0	0	1	0	0	2
Black Woodpecker	*Dryocopus martius*	0	0	1	0	0	0	0	1	2

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Osprey	*Pandion haliaetus*	0	0	0	0	1	0	0	1	2
Glaucous Gull	*Larus hyperboreus*	0	0	0	0	1	1	0	0	2
Mute Swan	*Cygnus olor*	0	0	0	0	0	1	1	0	2
Marsh Tit	*Poecile palustris*	0	0	0	0	0	1	0	1	2
Ring Ouzel	*Turdus torquatus*	0	0	0	0	0	1	0	1	2
European Stonechat	*Saxicola rubicola*	1	0	0	0	0	0	0	0	1
Thrush Nightingale	*Luscinia luscinia*	1	0	0	0	0	0	0	0	1
Eurasian Moorhen	*Gallinula chloropus*	1	0	0	0	0	0	0	0	1
Western Yellow Wagtail	*Motacilla flava*	1	0	0	0	0	0	0	0	1
Brant Goose	*Branta bernicla*	0	1	0	0	0	0	0	0	1
European Starling	*Sturnus vulgaris*	0	0	1	0	0	0	0	0	1
Great Gray Owl	*Strix nebulosa*	0	0	1	0	0	0	0	0	1
Ortolan Bunting	*Emberiza hortulana*	0	0	1	0	0	0	0	0	1
Ural Owl	*Strix uralensis*	0	0	1	0	0	0	0	0	1
Willow Tit	*Poecile montanus*	0	0	1	0	0	0	0	0	1
Eurasian Eagle-Owl	*Bubo bubo*	0	0	1	0	0	0	0	0	1
Spotted Redshank	*Tringa erythropus*	0	0	1	0	0	0	0	0	1
Red-throated Loon	*Gavia stellata*	0	0	0	1	0	0	0	0	1

Meadow Pipit	*Anthus pratensis*	0	0	0	0	1	0	0	0	1
Wood Lark	*Lullula arborea*	0	0	0	0	1	0	0	0	1
Yellowhammer	*Emberiza citrinella*	0	0	0	0	1	0	0	0	1
Great Egret	*Ardea alba*	0	0	0	0	1	0	0	0	1
European Honey-buzzard	*Pernis apivorus*	0	0	0	0	1	0	0	0	1
Common House-Martin	*Delichon urbicum*	0	0	0	0	1	0	0	0	1
Whimbrel	*Numenius phaeopus*	0	0	0	0	1	0	0	0	1
Red-necked Grebe	*Podiceps grisegena*	0	0	0	0	1	0	0	0	1
Black Guillemot	*Cepphus grylle*	0	0	0	0	1	0	0	0	1
Caspian Tern	*Hydroprogne caspia*	0	0	0	0	1	0	0	0	1
White-tailed Eagle	*Haliaeetus albicilla*	0	0	0	0	1	0	0	0	1
Yellow-browed Warbler	*Phylloscopus inornatus*	0	0	0	0	0	1	0	0	1
Water Rail	*Rallus aquaticus*	0	0	0	0	0	1	0	0	1
Barnacle Goose	*Branta leucopsis*	0	0	0	0	0	1	0	0	1
Horned Lark	*Eremophila alpestris*	0	0	0	0	0	1	0	0	1
Common Murre	*Uria aalge*	0	0	0	0	0	1	0	0	1
Red-throated Pipit	*Anthus cervinus*	0	0	0	0	0	1	0	0	1
Gray Partridge	*Perdix perdix*	0	0	0	0	0	1	0	0	1

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Sedge Warbler	*Acrocephalus schoenobaenus*	0	0	0	0	0	0	1	0	1
Common Eider	*Somateria mollissima*	0	0	0	0	0	0	1	0	1
Greater White-fronted Goose	*Anser albifrons*	0	0	0	0	0	0	1	0	1
Great Snipe	*Gallinago media*	0	0	0	0	0	0	1	0	1
Mediterranean Gull	*Ichthyaetus melanocephalus*	0	0	0	0	0	0	1	0	1
Canada Goose	*Branta canadensis*	0	0	0	0	0	0	1	0	1
European Turtle-Dove	*Streptopelia turtur*	0	0	0	0	0	0	0	1	1
Eurasian Jay	*Garrulus glandarius*	0	0	0	0	0	0	0	1	1
Lesser Spotted Woodpecker	*Dryobates minor*	0	0	0	0	0	0	0	1	1

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